RAINFALL RUNOFF SIMULATION USING MODIFIED SCS-CN AND HEC-HMS MODEL IN KUANTAN WATERSHED

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ABSTRACT

Kuantan watershed located in the flood prone area and experienced flood event almost every year due to monsoon season on the Peninsular Malaysia in month of November to February. Based on the condition of the watershed that has high probability in subjected to the flood occurrence, it shows that there was a need to develop a hydrologic model for the watershed. The study aims to develop the rainfall-runoff relationship using hydrological model and GIS in Kuantan watershed, assess the performance of HEC-HMS model in runoff prediction and evaluate the accuracy of modified SCS-CN in tropical area. HEC-HMS model was used to stimulate the storm event that occurs in the watershed based on the selected event where the calibration and validation also were carried out. The method used in the model was the SCS Unit Hydrograph for the Transform Method, SCS-CN as the Loss Method, and Lag Time as the Flood Routing Method. The simulation was carried out based on two selected storm event which was on the month of December 2006 and month of January 2012. The value of initial abstraction ratio used was 0.2 and 0.05 which the result based on both application of the ratio will be compared. The model was calibrated based on the antecedent moisture condition which considering the wet condition in the watershed which was known as AMC III, where the calculated curve number based on the land use and hydrological soil groups criteria was assumed in the normal condition. The efficiency of the simulated result over actual result was access using the Nash-Sutcliffe Efficiency (NSE). For the simulated result based on selected event, the NSE value for the model before and after calibration was range from 0.7 to 0.9 for both value of initial abstraction ratio which shows that the model perform well but the model seem to underestimate the actual peak discharge in the watershed. The efficiency for the model based on event on December 2006 was higher without calibration with initial abstraction ratio of 0.2 while for event on January 2012; the efficiency of the model was higher after the model calibrated which has almost the similar efficiency for both ratio of abstraction use. The application of two different equations to calculate the Lag Time also gives slight changes in the result as the used of Kirpich Equation gives a better result compare to the use of SCS Lag Equation for the prediction of the peak discharge.

ABSTRAK

Kawasan tadahan Kuantan terletak di kawasan yang sering dilanda banjir dan hampir mengalami peristiwa banjir setiap tahun kerana musim tengkujuh di Semenanjung Malaysia pada bulan November hingga Februari. Berdasarkan kepada keadaan kawasan tadahan air yang mempunyai kebarangkalian yang tinggi untuk dilanda banjir, ia menunjukkan bahawa terdapat keperluan untuk membangunkan model hidrologi bagi kawasan tadahan . Kajian ini bertujuan untuk membangunkan hubungan hujan dengan air larian menggunakan model hidrologi dan GIS di kawasan tadahan Kuantan, menilai prestasi model HEC-HMS dalam ramalan aliran dan menilai ketepatan SCS-CN yang diubah suai bagi kawasan tropika. Model HEC-HMS digunakan untuk mensimulasikan kejadian ribut yang berlaku di kawasan tadahan berdasarkan tarikh yang dipilih di mana penentukuran dan pengesahan akan dilakukan juga. Kaedah yang digunakan dalam model ini ialah SCS Unit Hydrograph untuk kaedah Transform, SCS-CN sebagai kaedah Loss, dan Lag Time sebagai kaedah Flood Routing. Simulasi ini dilakukan berdasarkan kepada dua peristiwa ribut yang dipilih iaitu pada bulan Disember 2006 dan bulan Januari 2012. Nilai nisbah abstraksi awal yang digunakan adalah 0.2 dan 0.05 dan hasil daripada kedua-dua nilai akan dibandingkan. Model ini telah ditentukan berdasarkan daripada keadaan kelembapan yg di kawasan tadahan air yang dikenali sebagai AMC III, di mana nilai CN yang dikira adalah berdasarkan penggunaan tanah dan kumpulan tanah hidrologi dan dianggap berada dalam keadaan yang normal. Ketepatan hasil simulasi ke atas data sebenar akan ditentukan menggunakan kaedah Nash-Sutcliffe Efficiency (NSE). Berdasarkan hasil simulasi, nilai NSE untuk model sebelum dan selepas penentukuran berada dalam julat 0.7-0.9 untuk aplikasi kedua-dua nilai nisbah abstraksi awal dan menunjukkan bahawa model menunjukan prestasi yang baik tetapi model seolah-olah memandang rendah pelepasan puncak sebenar dalam kawasan tadahan air. Kecekapan untuk model berdasarkan peristiwa pada Disember 2006 adalah tinggi untuk keadaan biasa dengan nisbah abstraksi 0.2 manakala bagi peristiwa pada Januari 2012; kecekapan model adalah tinggi selepas model ditentukur yang mempunyai hampir kecekapan yang sama untuk penggunaan kedua-dua nisbah abstraksi. Penggunaan dua persamaan yang berbeza untuk mengira Lag Time juga memberikan perubahan dalam keputusan di mana bagi persamaan Kirpich, ia memberikan hasil yang lebih baik berbanding dengan penggunaan persamaan SCS Lag untuk ramalan perlepasan puncak.

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LIST OF SYMBOLS

%	Percentage
km^2	Kilometer square
°N	North
°E	East
∞	Infinity
I_a	Initial abstraction
S	Potential maximum retention
Q	Direct runoff
P	Total precipitation
λ	Initial abstraction ratio
L	Basin Length
S	Slope of the basin
T_c / t_c	Time of concentration
t_l	Lag time
ft	Feet
Q_o , Q_S	Observed discharge, Simulated discharge
m	Meter
mm	Millimeter
m^3/s	Cubic meter per second
min.	Minutes
hrs	Hours

LIST OF ABBREVIATIONS

GIS	Geographic Information Systems
HEC-HMS	Hydrologic Engineering Center -Hydrologic Modeling System
SCS-CN	Soil conservation service - curve number
CN	Curve number
DID	Department of Drainage and Irrigation
HEC-GeoHMS	Hydrologic Engineering Center - GeoHydrologic Modeling System
NSE	Nash-Sutcliffe efficiency
AMC	Antecedent moisture condition
DEM	Digital elevation model
ASTER GDEM	ASTER Global Digital Elevation Model
HSGs	Hydrologic soil groups
SI	10% of Plastic Aggregate
AMC I	Antecedent moisture condition (Dry)
AMC II	Antecedent moisture condition (Normal)
AMC III	Antecedent moisture condition (Wet)
USACE	United States Army Corps of Engineers

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF STUDY

Rainfall occurrence is a natural process defines as the amount of precipitation of water form in the specific area and time interval which expressed in units of millimeters or inches. The precipitated water is measured using rain gauge that is set in the specific area that functions as rain collector. In some region, the rainfall not always fall in the liquid form but also including solid precipitation such as snow, hail. This may occur due to surrounding condition of the region and the common condition is due to the weather.

When rain falls onto the earth, the water flows from the highest peak to the lower places with some of the precipitation portion will infiltrating into the ground and replenish the groundwater and most of the precipitation will flows as a runoff. The common factors affecting the precipitation are the intensity and the duration of the rainfall or the storm. Higher rain intensity caused the soil to be saturated and rate of infiltration will decreased causing the excess water to fall as the runoff. The type of soil also affecting the runoff as the non-porous soil has lower rate of infiltration compare to porous soil. The rate of runoff also affects by other factors such as the present of plant and the local topography of the area.

Rainfall runoff may cause the occurrence of flooding as if the runoff from the storm is higher, it may exceeding the capacity of the stream capacity which will causing flooding. Runoff also contributes on the reduction of ground water recharge. Most of the drinkable water is extract from the groundwater sources. Overuse of the groundwater without natural replenishing or slower rate of replenishing due to runoff will cause the land to collapse which known as the subsidence process. The groundwater fills the spaces in the soil gives an internal strength to the ground. When the water is removed, it will leave an opening spaces filled with air. The absence of the internal strength will cause the soil structure to collapse and filled the spaces, thus destroying the groundwater aquifer. There also will be a decreased in the stream base flow due to the runoff. Base flow is the water that continuously flows even on the dry periods. This flow is vital for the survival of the aquatic life in the stream. Other than that, runoff also increased the soil erosion and reduction of natural filtration of the water.

Hydrological modeling is important for watershed management as hydrology is the driving force behind many processes occurring on the watershed (Albek et al., 2004). The modeling is used for the purpose of forecasting and predicting flood peaks and runoff volumes due to heavy rain. The modeling of the model can be conduct and it can be used as a virtual model associated to the real condition which can be used to investigate the changes to the depth of the rainfall and the rate of runoff in the study area. For this modelling, simulating process is carried out using the HEC-HMS method with the modified SCS-Curve Number as the loss model, Lag method as the flood routing approaches and Constant Monthly as the base flow method. The parameter of the study area is delineated using the Geographic Information Systems (GIS) which is important as an input for the simulation process. The Soil Conservation Service curve number method, SCS-CN is essentially an empirical, one-parameter CN event rainfall-runoff model. It is a dimensionless curve number which takes into account the effects of land use/cover, soil types, and hydrologic soil groups on surface runoff, and basically will relates the direct surface runoff to rainfall in the watershed. The SCS-CN method has been widely used for estimating rainfall-generated surface runoff in watershed hydrologic modeling (Chu and Steinman, 2009). An importance aspect of watershed modelling processes is the ability to determine and obtain various parameter inputs for the watershed. Information on precipitation, soil properties, and land use/cover is of critical importance to watershed modelers and managers (Daniel et al., 2010).

For this research, a rainfall event data that occurred in Kuantan was selected to be used in the simulation. The selected rainfall event was used to setup the hydrologic model for the Kuantan watershed. The accuracy of the result can be analysis by comparing the simulated discharge to the actual discharge data from the stream flow station. Through this, I will be able to develop the rainfall-runoff relationship in Kuantan watershed. The relationship between rainfall and runoff is essential in a catchment for hydrologic analysis and design (Chang, 2009). The rainfall will change runoff in term of surface-runoff, interflow and base-flow after it subjected to losses due to evaporation, transpiration, interception and infiltration. The rainfall-runoff usually influenced by factors such terrain condition, geology condition, soil type, area, slope, and plant-types in the watershed.

Based on the developed model, the performance of the HEC-HMS model in the runoff prediction can also be assess by comparing the simulation data with the observe data. The model will performed well if the simulated result is almost fit to the observed data. Apart from that, Kuantan river basin is located in a tropical region which consists of wet and dry season throughout the year-round. Therefore, by using the develop model, the accuracy of the modified SCS-CN as the loss model on the runoff prediction on the tropical region can be evaluate based on the result obtained from the simulation.

1.1 PROBLEM STATEMENT

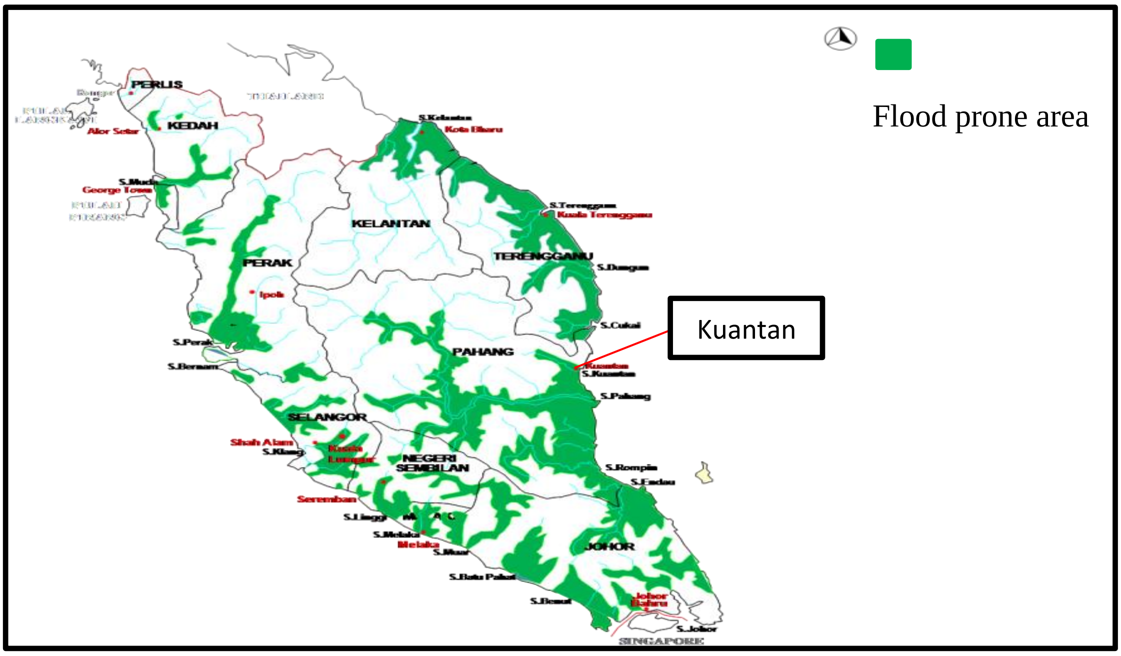

Figure 1.0: Flood prone area in Peninsular Malaysia (DID, Malaysia)

Malaysia has experienced extreme rainfall events during the monsoon seasons that last for several hours and lead to flash flood (Win and Win, 2014). The monsoon season is usually in the month of November until February which causing the increase number of flood events in several areas in the Peninsular Malaysia. Figure 1.0 shows the area of interest for this study which showing that Kuantan region is located in the flood prone areas in Peninsular Malaysia, which mean that flood is the main natural disaster, occur in the area. Malaysia has experiences many floods event before as a result of prolonged rain in some parts of Peninsular Malaysia which has brought negative impact to environment and society. Oversee the flood problem in the Kuantan area, it shows that there is a need to create a simulation model for the area to help in the estimation of discharge for the study area. Hydrological models are important for a wide range of applications, including water resources planning, development and management, flood prediction and design, and coupled systems modelling including, for example, water quality, hydro-ecology and climate (Pechlivanidis et al., 2011).

The runoff from the storm event also can be affected by the major land use changes for the study area as time pass by. The land use properties will be pair with the hydrologic soil groups which will produce the curve number map. Major land use changes as the time pass by will affect the value of the curve number for the study area which can affect the calculation or simulation calculation. Higher value of the curve number will significantly increase the result obtained in the simulated data

By using HEC-GeoHMS, the rainfall–runoff model for Kuantan watershed can be process as an input for HEC-HMS software. In the HEC-HMS, the simulation can be run in order to predict the discharge for the Kuantan watershed. By doing that, the hydrological parameters of Kuantan watershed can be obtained and the relationship between the relationship between observed flow and simulated flow due to extreme rainfall events can be access. The estimated discharge can be used as the guide in hydrologic design in the study area as a guideline in the flood mitigation works which can reduce the impact of flood in Kuantan. The analysis and prediction of flood hydrograph in a watershed can also bring benefit to the conservation of water resources and flood planning and mitigation in Kuantan, as well as the soil engineering planning.

1.2 OBJECTIVES

a) To developed the rainfall-runoff relationship using hydrological model and GIS in Kuantan watershed.
b) To assess the performance of HEC-HMS model in runoff prediction
c) To evaluate the accuracy of modified SCS-CN in tropical area

1.3 SCOPE OF STUDY

Pahang River Basin, which is the largest river basin in Peninsular Malaysia, covers a catchment area of 29,000 km^2. Kuantan is the state capital in Pahang and known as the third largest state in Peninsular Malaysia and located between 3°49’00”N and 103°20’00”E (3.81667°N and 103.33333°E). The total area of Kuantan is 2960 km^2 with the elevation of 21.95 m. The river bed slope information in the Pahang area is Sungai Pahang (0.016% (1/6200), Sungai Jerai (0.034% (1/2900)) and Sungai Tembeling (0.024% (1/4100) Kuantan experienced rainy season between the month of December until February and subjected to flood event. The area in Kuantan that subjected to flooding includes the path to Sungai Lembing and few areas along Kuantan River.

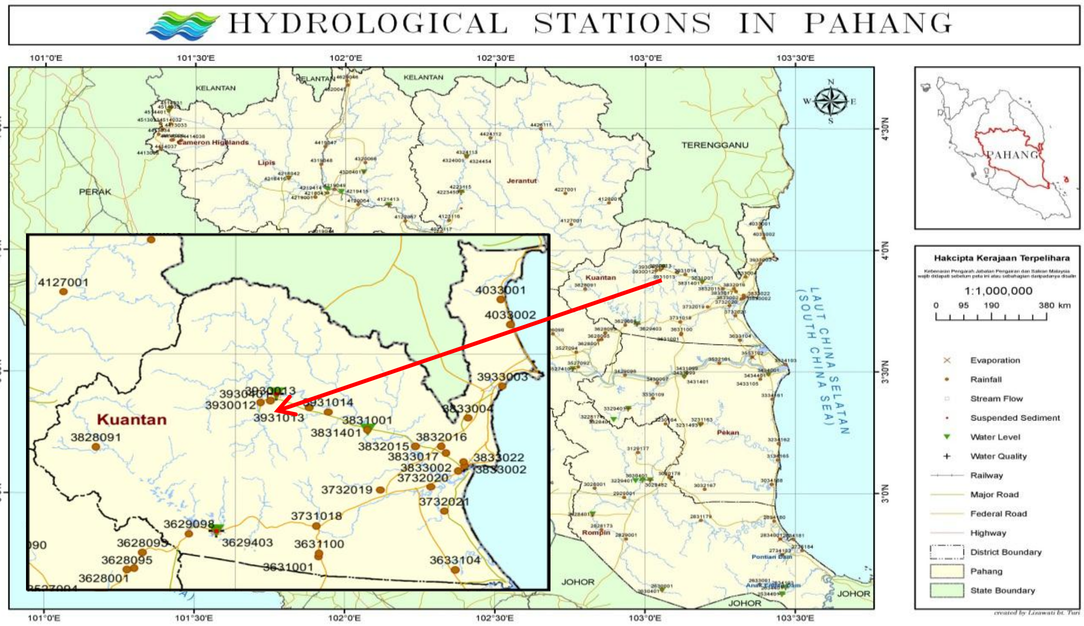

Figure 1.1: Distribution of rainfall stations in Kuantan, Pahang (DID, Malaysia)

STATION NO.	STATION NAME	FUNCTION	STATE	DISTRICT	RIVER	RIVER BASIN	LAT.DEG	LONG.DEG
3930012	Sg. Lembing P.C.C.L Mill	Rainfall	Pahang	Kuantan	Sg. Lembing	Sg.Kuantan	3.916666667	103.0361111
3930401	Sg. Kuantan, Bukit Kenau	Stream flow	Pahang	Kuantan	Sg.Kuantan	Kuantan	3.931944444	103.0583333

Table 1.0: Hydrological stations in Kuantan used in the study (DID, Malaysia)

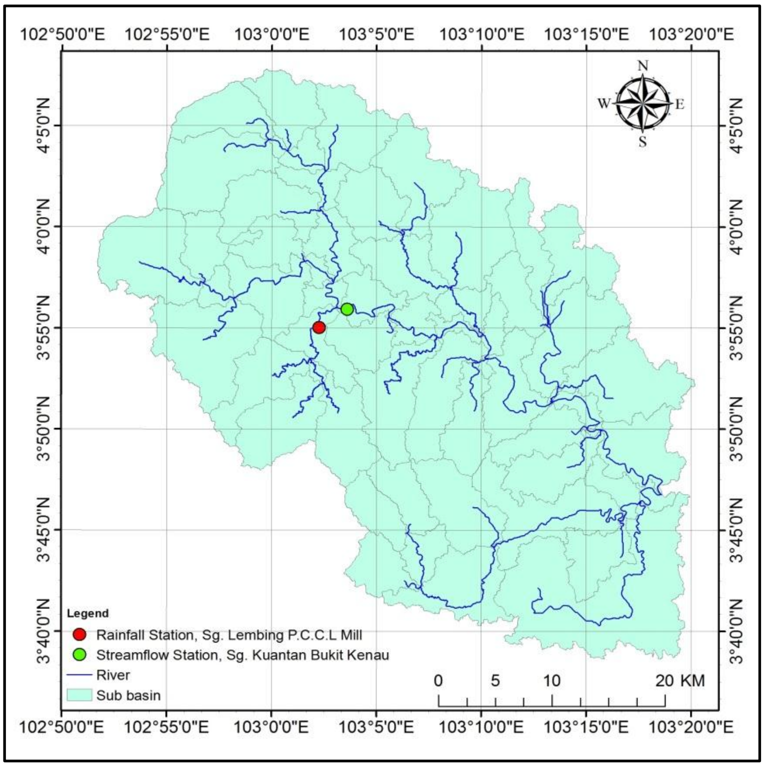

Figure 1.2: Watershed boundary and location of hydrological stations in Kuantan watershed used in the study

Figure 1.1 shows the distribution of rainfall stations in the Kuantan river basin in Pahang state. Table 1.0 and Figure 1.2 show the boundary of Kuantan watershed with the hydrological stations and it location in the watershed used in the study which were generated in the ArcMap. The rainfalls events data is collected through the rainfall station. To stimulate the rainfall-runoff, the data from the station which related to the rainfall events needed to be collected from Department of Irrigation and Drainage. Through the analysis of observed rainfall hydrographs and hyetographs, the selected rainfall events are used in the simulation in HEC-HMS model. However, not all the rainfall data from each station will be use since some rainfall station is not in the boundary of Kuantan watershed while some station mostly have an error in it reading, mostly due to the instrument error. The data from the streamflow station will be used to compare the simulated result with the observed result. Due to location of the streamflow station is located at the upper catchment which is at Sungai Kuantan in Bukit Kenau, the result of the outflow will be taken from the nearest junction from the streamflow station. Only rainfall data from one rainfall station also will be use due to the availability of the data is good at that particular rainfall station based on the selected events.

Based on the researched, the main task is to run a simulation run based on the created model in GIS application. In order to run a simulation, the important step is to produce a model as an input for the HEC-HMS. The model of Kuantan watershed will be created in the ArcMap which will involve with delineation process, parameterization procedure and model export. The Kuantan Watershed has a total of 59 sub basins in the watershed. The model export is basically a final step that will create an input file for the HEC-HMS from the ArcMap. In order to associate parameter of the land use and hydrological soil group with the basin, the next step is to produce a curve number map which is used in the ArcMap to calculate the value of curve number for each sub basin the watershed. Some of the parameter needed in the HEC-HMS for the model to run will be computed in the ArcMap automatically while some other parameter such as Lag Time for the routing method will be computed manually.

After the model of the Kuantan Watershed is exported to the HEC-HMS, the simulation process will be carry out and the simulated result will be compare with the observed result from the streamflow station to access the behaviour of the model. The input data for the model to run is the rainfall data, which selected based on the event of flood. In order to ensure the model to work accurately, the model calibration need to be done so the simulated result relatively matching the observed result. The model calibration is done by changing the model parameter such as the curve number. The model was calibrated for the identified sensitive parameters to improve the agreement between the simulated and observed data (Roy et al., 2013). The model efficiency will be evaluated using the factor such as the initial abstraction ratio and antecedent moisture condition. The efficiency of the model generated in this study will be evaluated using the Nash-Sutcliffe efficiency (NSE) method.

1.4 SIGNIFICANT OF STUDY

Malaysia experiences many major floods event in the past few years due to prolong rainfall occurrence. The flood occurrence has causing many negative impacts to the society such as properties loss and affecting the water quality. Due to the flood problem, Malaysian government has spent a lot of money in the flood mitigation work to reduce the impact of flood to the society. Flood occurrence is usually cause by the runoff of rainwater which occur because of the rain volume exceeding the storage capacity in the natural and artificial storage. The process of rainfall-runoff will be influenced by terrain, geology, soil, area, slope, and plant-types (Chang, 2009).

The modelling of the rainfall produces the flood hydrograph prediction which gives contribution to many aspects such as the hydrological planning and managing of flood event. The estimated rainfall also can be used as the guide in hydrologic design of rainfall runoff models. The computation of loses using the SCS-CN loss model also makes us understand more about runoff generation process and study the factors affecting rainfall runoff which can lead to flood. Besides that, the rainfall-runoff relationship is important for hydrological analysis and design. The information generates from the study can provides information important for the regulate the increase volume of the runoff, flood events, evaluation and upgrade of existing hydraulic structure from the changing in the hydrological data and contributes to flood mitigation works process.

1.5 LAYOUT OF THESIS

The thesis consist of five different chapters that and each chapter consist if own purposes. In the first chapter which is the introduction to the study, it generates general information about the study area. It then follows by the scope of study which determines the limit area of researched in term of location and method use. The problem statement indicates the purpose of the study been carried out which is derived from the background of study and the objectives for the study is set from the problem statement. The objectives of the study are the guideline that guides us along with our research. The significant of study indicates the contribution and effect of the research to the interested area of study.

The second chapter is the literature review, in which the researcher extracts information from the related study in the field. The review help me to understand more about the researched topic and what result should I expect from the study. The keyword that I used to searched for the related journal are the rainfall-runoff, HEC-HMS, SCS-CN, modified SCS-CN, and runoff modelling. The review will help in further understanding of the area of study and help to guide me to the correct direction during my research.

The third chapter is the methodology, which is the method I used in this study. The method I used in this study is the HEC-HMS modelling software with the calibrated or modified SCS-CN loss model to generate the runoff model for the study area. The delineation of the study area is done using GIS application which generates the data I needed before I run the simulation using HEC-HMS model.

Chapter 4 focuses on the experimental work or the simulation run process by the model after all the related information and component need in the model has been achieved. The result from the simulation then will be used to generate a curve number and computing runoff volumes using which will be compare with the observed data.

Finally, the data and result from the study will be summarized in chapter 5 and conclusions will be made whether the objectives of the study is achieved or not.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Many researched have been conducted for several years to study the rainfall characteristic and effects of the rainfall event to the surrounding using the HEC-HMS method with SCS-CN as the loss model. The Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) simulates the precipitation-runoff processes of watershed systems (Yuan and Qaiser, 2011). The Curve Number for the study area is determining by factors such as the land use and hydrological soil groups. Prior to the previous rainfall in the watershed which in cooperate with moisture condition; the antecedent moisture condition (AMC) for the development of CN Grid of the area also will need to be taken also. It is apparent that the CN-variability is primarily attributed to the antecedent moisture, and it has led to statistical and stochastic considerations of the curve number, undermining the physical basis of the SCS-CN methodology (Sidoeun et al., 2013). In cooperation of AMC with the curve number also allow sudden increase and decrease of the curve number variation. HEC-GeoHMS was used to delineate the watershed which provide input model for the HEC-HMS. By using HEC-HMS, the simulation of the selected watershed will be run and the simulation data will be comparing with the observed data. Rainfall simulation is also an effective technique to gather hydrologic data for different types of soil-vegetation-land use combinations (Narayan et al., 2012). The model efficiency in running the simulation will be evaluated based on the Nash–Sutcliffe model efficiency coefficient. The Nash–Sutcliffe Efficiencies can range from -∞ to 1, which is the nearer the value of NSE to efficiency of, the higher the accuracy of the model.

2.1 APPLICATION OF GIS FOR WATERSHED DELINEATION

Geographic Information Systems is a computer-based tool that use for purpose of mapping and analyzing. The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the geo-referenced data (Bakir and Xingnan, 2008). It also permits GIS to function as an effective planning tool by making hydraulic data easily transferable to floodplain management, flood insurance rate determination, economic impact analysis, and flood warning systems (Tabyaoui et al., 2011)

A watershed describes the portion of land which contains a common set of rivers and streams which all drain into a single large body of water, such as a lake, a larger river or an ocean (Mallikarjuna and Lakshmi, 2014). A digital representation of the watershed is provide by GIS which can be in-cooperate with which the hydrological modelling. Hydraulic modelling is an important process because in can help in the activity such as hydrological planning and conservation of the water resources. On the uses, GIS will produce two types of data which are the vector data (Shape files) and the raster data (Grids, TINs (Triangulated Irregular Networks) and Image) which will be used in the hydrological model. GIS offers technologically suitable method for land resource assessment, delineating different land use patterns, flood management, irrigation water management, and assessment and monitoring of environmental impact of watershed projects (Aher et al., 2014).

ArcHydro Tools is an extension in ArcGIS and it is used to delineate the sub-basins along with the river flow network on the watershed from the digital elevation model (DEM) of the catchment while HEC-Geo HMS is an extension used to carry out parameterization process along with the model export. The processing of the Digital Elevation Model (DEM) to delineate the watersheds is known as the terrain pre-processing which in this researched, the process is done using ArcHydro Tools extension in the GIS application. The digital elevation model extracted from the ASTER Global Digital Elevation Model (ASTER GDEM) which has the spatial resolution of 30 m. The DEM is use to delineate the watershed as the drainage surfaces, stream network, sub basins and the longest flow along with the topographic parameters such as the watershed terrain slope, river slope and the length and area of the parameter in the watershed. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation (Alaghmand et al., 2012). The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed (Hasan et al., 2009).

The Curve Number (CN) for a watershed can be estimated as a function of land use, soil type and antecedent watershed moisture (Feldman, 2000) and will be associated to the delineated basin in order to compute the curve number for each sub basin. The advantage of runoff estimation using curve number method for a drainage basin are accounted by those interactive factors in combination of land use, soil, and antecedent soil moisture condition (AMC) (Amberber, 2014). HEC-GeoHMS provides an integrated work environment with data management and customized toolkit capabilities, which includes a graphical user interface with menus, tools, and buttons (Hasan et al., 2009). HEC-GeoHMS creates background map files, basin model files, meteorological model files and a grid cell parameter files which can be used in HEC-HMS to develop a hydrological model (Fleming and Doan, 2009).

2.2 HEC-HMS MODEL

2.2.1 INTRODUCTION

HEC-HMS is hydrologic modeling software developed by the US Army Corps of Engineers Hydrologic Engineering Centre (HEC). HEC-HMS uses separate sub-models to represent each component of the runoff process, including models that compute rainfall losses, runoff generation, base flow, and channel routing (Du et al., 2012). HEC-HMS can help to set up the hydrologic model system and simulate the rainfall-runoff process of a watershed (Chang, 2009). A GIS companion product called the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) has been developed to aid in the creation of basin models and meteorological models for use with this software (Gautam, 2014).